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Transfer of Learning Between a Small Technically Advanced Aircraft and a Commercial Jet Transport Simulator

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Abstract

This study examines the extent to which skills acquired using advanced avionics found in a small technically advanced aircraft (TAA) transfer to more sophisticated equipment found in a modern jet transport. Eight pilots were trained to proficiency on twenty-eight procedures using the GPS navigation computer, autopilot, and flight director system found in a small technically advanced aircraft. Eight other pilots did not receive the training. All sixteen pilots were then tested on their ability to perform the same procedures using a computer-based simulator of the flight management and guidance systems found in a popular jet transport. Pilots attempted the jet transport procedures with no prior exposure to the equipment, no training, and no reference materials. Pilots who received the TAA training successfully completed 83% of all procedures in the jet transport, while pilots in the control group achieved an average success rate of 54%. Further analysis of the data showed that much of the control group's success was attributable to superficial strategies guided by labels that appear on the knobs and buttons of the equipment, and that their scores averaged only 22% on procedures for which no label cues were available. The results cast a strong vote for transfer of learning between the two types of equipment, and for the use of small technically advanced aircraft to train pilots who will later transition to the commercial jet fleet.

Introduction

Among the challenges of transitioning from small piston training airplanes to the commercial jet fleet is the requirement of learning to use the advanced avionics systems found in the modern commercial jet cockpit. Commercial air carriers have long struggled with training pilots who transition from the general aviation environment, or from other non-glass cockpit equipped aircraft (Wiener, 1985; Sarter & Woods, 1995; Palmer, Hutchins, Ritter, & van Cleemput, 1993; FAA, 1996; Risukhin, 2001; Billings, 1997; ATA, 1997; ATA, 1998, ATA, 1999).

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Many of the advanced avionics systems found in commercial jet aircraft are now becoming widely available in small general aviation aircraft. The current generation of small *technically advanced aircraft* (TAA) offers less-sophisticated versions of the same equipment found in the commercial jet fleet. Figures 1 and 2 offer a simple comparison between the capabilities of current-generation commercial jets and small technically advanced aircraft. Both airplanes offer the same basic configuration of navigation computer, multifunction displays, flight director, and autopilot systems.

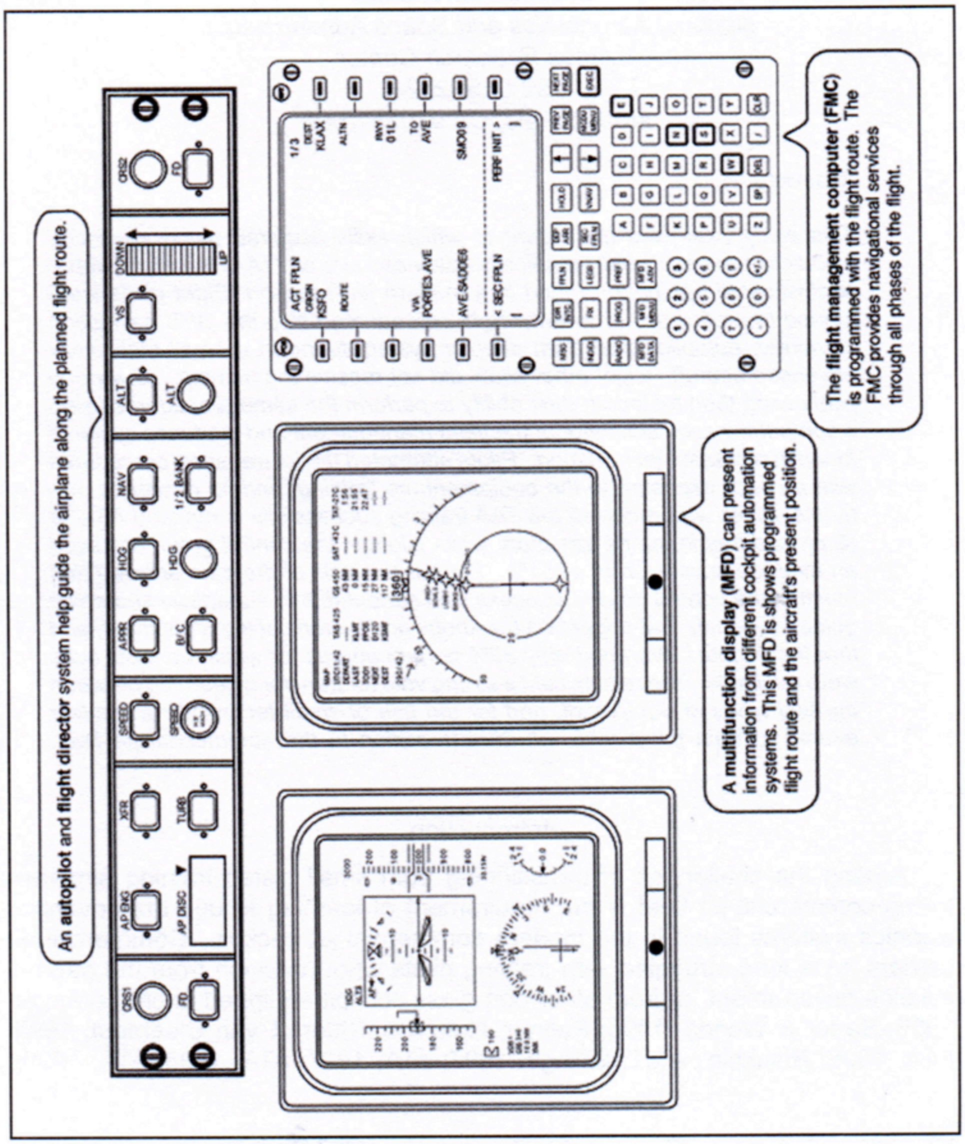

Figure 1.

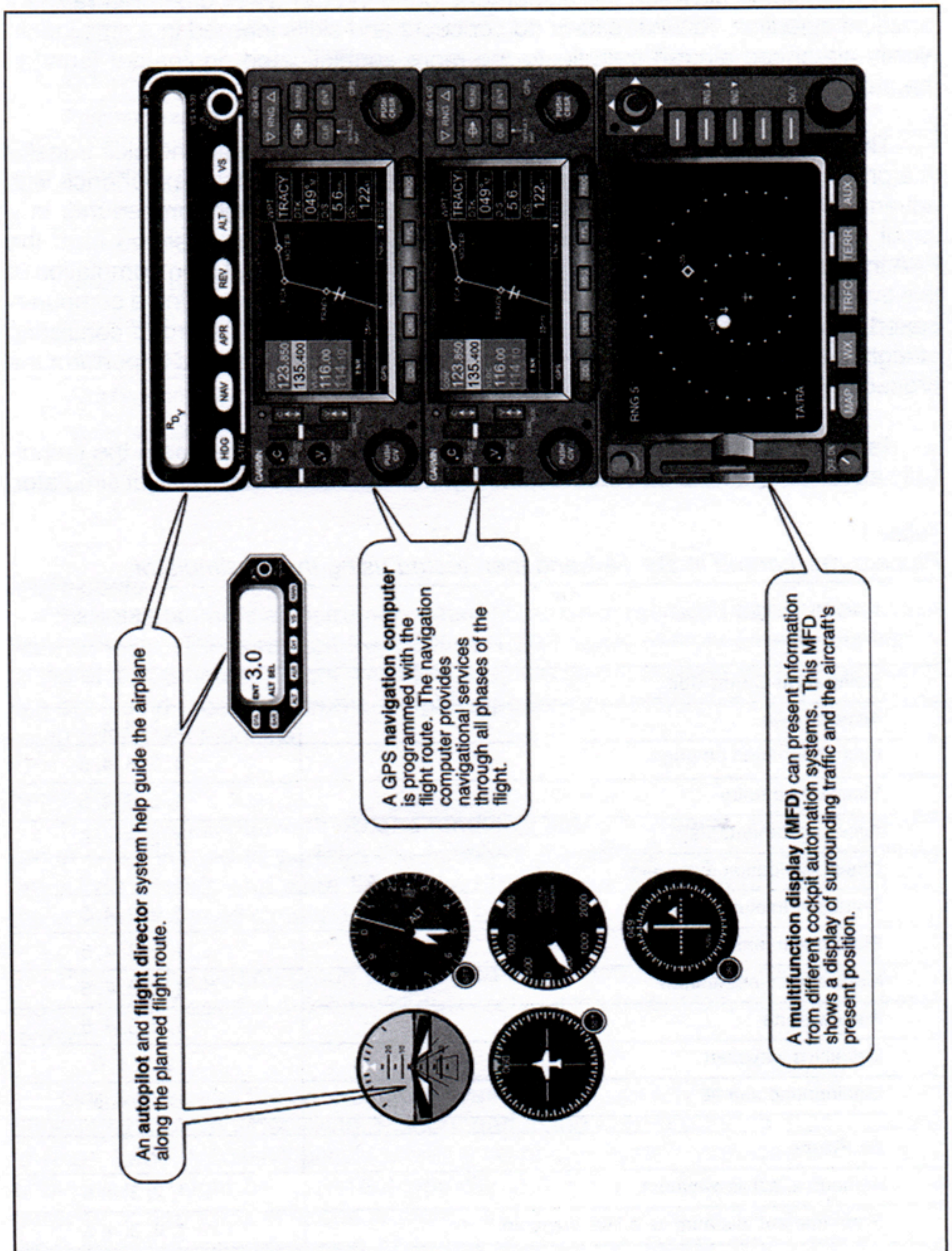
HDG
NAV
APR
REV
ALT
VS
An autopilot and flight director system help guide the airplane along the planned flight route.
A GPS navigation computer is programmed with the flight route. The navigation computer provides navigational services through all phases of the flight.
A multifunction display (MFD) can present information from different cockpit automation systems. This MFD shows a display of surrounding traffic and the aircraft's present position.

Figure 2.

The similarity between the equipment found in both types of aircraft raises a practical question: To what extent do concepts and skills learned in a small technically advanced aircraft transfer to the more sophisticated equipment found in the modern jet transport?

This study aims to answer this question about knowledge and skill transfer in a practical way. Eight instrument-rated pilots with no previous experience with advanced avionics were trained to proficiency on twenty-eight procedures in a small technically advanced aircraft. These procedures were derived from the FAA Instrument Rating Practical Test Standards (FAA, 2004). Upon completion of this training, pilots were asked to perform the same procedures using a computer-based simulation of a popular jet transport airplane. A control group consisting of eight pilots who did not receive the TAA training was also asked to perform the procedures in the commercial jet simulator.

Table 1 shows the procedures that pilots were asked to master in the technically advanced aircraft, and later asked to perform in the commercial jet simulator.

Table 1
Procedures learned in the TAA and then tested using the jet simulator.

PROCEDURES	SESSIONS
Navigation Computer	
Access page	1, 2, 3, 4, 5
Find information on page	1, 2, 3, 4, 5
Simple data entry	1, 2, 3, 4, 5
Access extended page	1, 2, 3, 4, 5
Check navigation database	1, 2, 3, 4, 5
Database lookup	1, 2, 3, 4, 5
Enter origin and destination	1, 2, 3, 4, 5
Menu select procedures	1, 2, 3, 4, 5
Review route	1, 2, 3, 4, 5
Set active waypoint	2, 3, 4, 5
Set inbound course	2, 3, 4, 5
En Route	
Announce active waypoint	1, 2, 3, 4, 5
Find time and distance to active waypoint	1, 2, 3, 4, 5
En Route Modifications	
Direct to	2, 3, 4, 5
Add waypoint	1
Delete waypoint	1

Multiple holds	3, 4, 5
Program hold	3, 4, 5
Exit hold	3, 4, 5
Program crossing restriction	2, 4, 5
Autopilot	
Altitude pre-select	4, 5
Engage Vertical Speed function	4, 5
Determine necessary vertical speed	4, 5
Fly heading using Heading Select	4, 5
Verify engaged mode	4, 5
Arm Nav function	4, 5
Verify Nav armed	4, 5
Constant speed descent	4, 5

Method

Participants

Sixteen commercial instrument-rated pilots were recruited from several local flight schools. Pilots ranged from 300 to 1,600 hours of flight experience with a mean of 1,106 hours. Pilots were told they would not be paid for their participation but would receive instrument flight experience or simulated flight experience using advanced avionics.

Procedure

The sixteen pilots were divided randomly into two groups. Pilots in the TAA group were trained to perform the twenty-eight procedures in small technically advanced aircraft, and were then asked to perform the same procedures using the computer-based simulator of the jet transport.

Pilots in the control group were asked to perform all of the procedures using the computer-based simulator, without receiving the technically advanced aircraft training.

One purpose of the control group was to factor out any successes that might be enjoyed due to what Irving, Polson, and Irving (1994) referred to as *label following*. Label following occurs when a computer system provides simple cues about how it might be operated, typically in the form of labels that suggest the purpose or operation of knobs, buttons, and dials on the equipment. When using label following, operators can often succeed in completing a task without any knowledge or skill related to that task. For example, consider the task of calling up the Index page on the control display unit (CDU) shown in Figure 3. A person with little or no knowledge about this system might notice the button labeled INDEX, shown on CDU, and correctly hypothesize that pushing this button will accomplish the task.

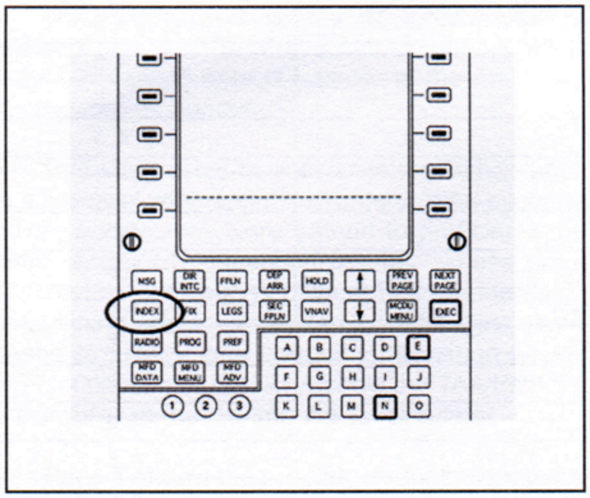

Figure 3.

Although label following cues are legitimate components of expert performance, we would like to distinguish between success attributable to true understanding of the system and tasks, and success due to label following.

Technically advanced aircraft training. For the eight pilots participating in the TAA training group, the technically advanced aircraft training occurred in five scheduled sessions that covered the 28 procedures listed in Table 1.

Prior to each session, each pilot was told to read a technical publication (Casner, 2002) that described the concepts and skills required to perform any new procedures that would be covered during that session. Pilots were told to master the material as best as they could, and that during the upcoming session, they would have the opportunity to demonstrate and practice their newly learned procedures in flight. Pilots were told that they would also be given an opportunity to practice all of the procedures that they had learned during the previous sessions. The second column in Table 1 shows the sessions in which each procedure was practiced. Note that some procedures were practiced only during one or two sessions during the course of the training. Note also that no new procedures were introduced during the fifth session as this session was intended as a "check flight" to ensure that all pilots understood and were able to perform all procedures.

During each session, the experimenter briefly reviewed the procedures that would be practiced during the flight, provided the pilot with charts covering the routes and approaches to be flown, and answered any questions the pilot had about the reading.

During each dual-instruction flight, the experimenter rode in the right seat but did not operate the controls. A script for each flight was prepared in advance and used by the experimenter to ensure that each pilot was presented with the same procedures in the same order.

The jet transport simulator evaluation. Following the conclusion of the TAA training sessions, all sixteen pilots participated in a session in which they were asked to perform the same 28 procedures shown in Table 1 using a computer-based simulation of the cockpit of a popular jet transport airplane. Again, eight of the pilots had received the technically advanced aircraft training and eight had not. It was explained to all sixteen pilots that no training on the jet transport systems would be provided, nor would pilots have the opportunity to access any reference materials for the systems. The aim of the study was to determine to what extent pilots' existing knowledge could help guide them through the procedures. The TAA training group had their instrument flying skills together with their technically advanced aircraft training. The control group had their instrument flying skills to guide them, together with any label following cues present on the jet transport equipment.

During the jet transport simulator session, pilots were presented with procedures and asked to do their best to perform them without asking for intervention from the experimenter. If the pilot was able to successfully complete a procedure, a score of 1 was recorded for that procedure. If an error was made, a score of 0 was recorded for the procedure. If an impasse was encountered, pilots could ask for intervention, these interventions were recorded, and a score of 0 was recorded for the procedure. If a pilot was unsuccessful on a particular procedure, the experimenter demonstrated the procedure before moving on to the next. Since the jet transport travels as much as five times faster than the piston airplane, the simulation was frozen while the experimenter took the time to provide the needed interventions. A paper scorecard was used to record scores for each procedure.

Results and Discussion

Overall Performance

A first question posed by the experiment is the extent to which performance for procedures performed in the jet simulator was leveraged by the technically advanced aircraft training. Figure 4 shows a graph of the proportion of procedures successfully completed by each pilot using the jet simulator. The data in Figure 4 represent individual scores (proportions for all 28 procedures combined) for the sixteen pilots. The pilots who received the technically advanced aircraft training performed significantly better than the control group ($df = 14$, $t = 7.72$, $p < .0001$).

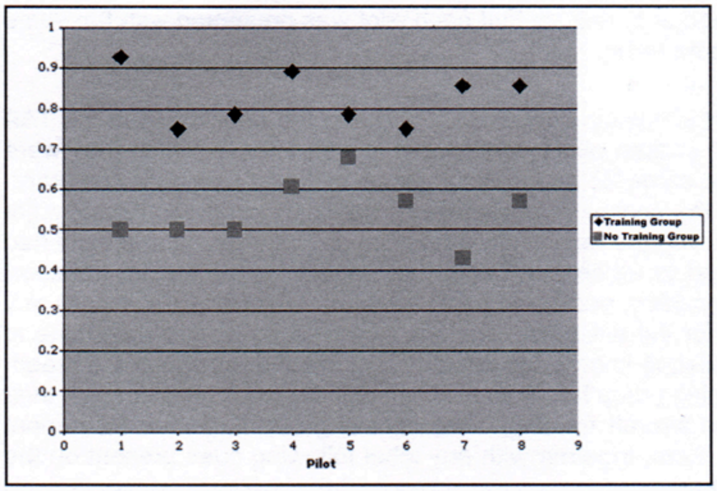

Figure 4. Individual scores for both groups for the jet simulator procedures.

The overall performance of the TAA training group casts a vote for the transfer of knowledge and skill from the small technically advanced aircraft to the jet. These pilots were able to successfully perform 83% of all procedures on the jet on the first try.

Success Due To Label Following

The mean success rate of 54% for the control group prompts the question of to what extent their success was attributable to label following. To answer this question, procedures were segregated into two categories, those for which label cues appeared on the equipment, and those for which no cues appeared. The graphs in Figures 5a and 5b show the results for the TAA training and control groups on label-cued and non-label-cued procedures.

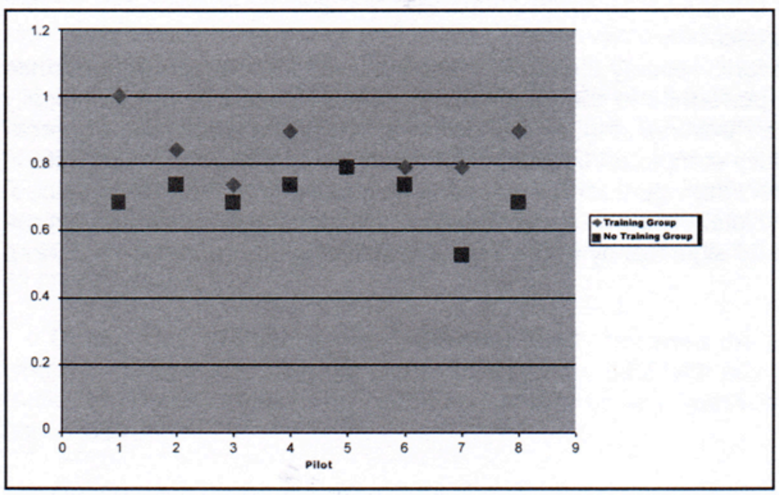

Figure 5a. Individual scores for procedures with label cues.

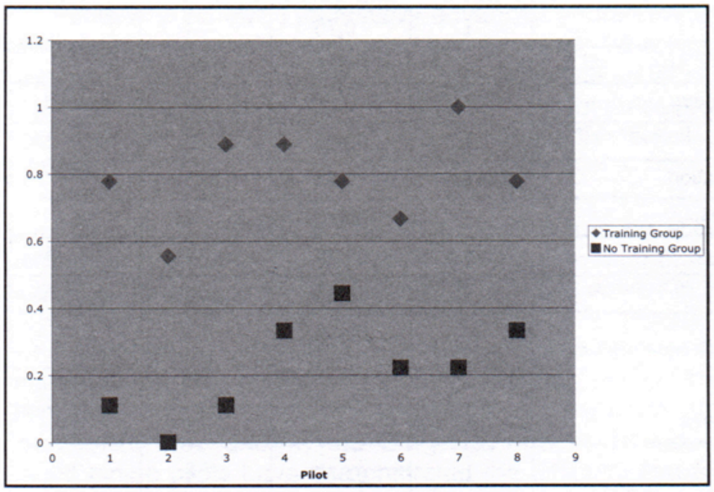

Figure 5b. Individual scores for procedures without label cues.

A 2-way analysis of variance (ANOVA) reiterated the main effect of the advantage due to receiving the TAA training (F=76.3, p < .0001), a main effect due to the presence of label cues (F=41.2, p < .0001), and a significant interaction between the two factors (F=27.0, p < .0001).

For the pilots who received the TAA training, the same ANOVA revealed no significant effect due to presence or absence of label cues, suggesting that the cues provided by pilots' own knowledge were as strong as the cues provided by the labels. The pilots who did not receive the TAA training performed well when label cues were present but poorly in the absence of label cues. This suggested that their successes occurred in the absence of understanding of how to operate the systems. Lastly, the pilots who received the TAA training performed significantly better than their control group counterparts on tasks for which label following was possible. This suggested that the TAA training group imparted knowledge on tasks even when label cues were present, and this knowledge led to significantly better performance.

Breakdown By Procedure

Table 2 shows the results (across all pilots) for the twenty-eight individual procedures on which all pilots were tested.

Table 2
Average scores for the two groups on each of the 28 procedures tested in the jet simulator.

TASKS PERFORMED USING THE JET SIMULATOR	Labels	Control Group	Trained Group	t-test
Navigation Computer				
Access page	L	1	1	
Find information on page	**L**	1	1	

Table is continued on following page

Simple data entry	L	0.75	1	
Access extended page		0.375	0.75	
Check navigation database	L	0.25	0.875	$p < .01$
Database lookup	L	0.625	0.625	
Enter origin and destination	L	0.75	0.875	
Menu select procedures	L	0.875	1	
Review route	L	0.875	1	
Set active waypoint		0.25	0.875	$p < .01$
Set inbound course		0.125	0.5	
En Route				
Announce active waypoint	L	**1**	**1**	
Find time and distance to active waypoint	L	0.875	1	
En Route Modifications				
Direct to	L	0.75	0.875	
Add waypoint		0.125	0.75	$p < .01$
Delete waypoint		0.25	0.875	$p < .01$
Multiple holds	L	0.375	1	$p < .01$
Program hold	L	0.25	0.5	
Exit hold	L	1	0.875	
Program crossing restriction	L	0.5	0.5	
Autopilot				
Altitude pre-select	L	0.125	0.25	
Engage Vertical Speed function		0.125	0.875	$p < .01$
Determine necessary vertical speed		0.375	0.875	$p < .05$
Fly heading using Heading Select	L	0.75	0.75	
Verify engaged mode	L	0.5	0.875	
Arm Nav function		0.375	0.875	$p < .05$
Verify Nav armed		0	0.75	$p < .01$
Constant speed descent	L	1	1	

Our hypothesis was that pilots who learned the 28 procedures during the TAA training would perform well on the same procedures on the jet transport simulator. The data in Table 2 show that pilots in the TAA training group enjoyed at least a 50% success rate on 27 of the 28 procedures, and at least a 75% success rate on 23 of the 28 procedures. Overall, the results cast another vote of confidence for the hypothesis that the technically advanced aircraft training positively transferred to the jet simulator.

Pilots who received technically advanced aircraft training performed significantly better than the control group on nine of the 28 procedures. Among these nine procedures, seven were procedures for which no label cues were available. This result strongly suggests that pilots' success for these procedures was derived from concepts and skills they had learned during the technically advanced aircraft training.

It is also interesting to note that the TAA training failed to leverage pilots' performance on the Altitude preselect task, even though both the concepts and button-pushing steps for this procedure are quite similar in the two aircraft.

The following six procedures are required to perform the "course intercept" maneuver required by the instrument rating practical test standards: Fly heading using Heading Select, Verify engaged mode, Set active waypoint, Set inbound course, Arm Nav function and Verify Nav armed. Previous studies with experienced airline pilots have demonstrated the difficulty that pilots encounter when learning to perform the course intercept maneuver using advanced avionics (Irving, Polson, & Irving, 1994). The course intercept procedure combines several advanced concepts such as the notions of departing and rejoining the planned route, and armed vs. engaged autopilot modes. Slightly fewer than 70% of Irving et al's airline pilots who had just completed an airline initial training course on a Boeing 737 were able to successfully complete this procedure following explicit training using the same equipment used for the test. Pilots who completed the technically advanced aircraft training completed this collection of procedures successfully 77% of the time, using equipment they had never seen before. The control group was successful 33% of the time.

It was noted earlier that some procedures were only practiced once or twice during the course of the TAA training. The aggregate success rate for these procedures was 75%, while the mean for the remaining procedures, which were practiced either four or time times during the course of the training, was 83%. There was no significant difference between these means.

Correlating Total Flight Time and Performance with Cockpit Automation

A last interesting analysis is to look at the relationship between the total flight experience of each pilot and their scores for the jet transport procedures. For the group that received the TAA training, the correlation was –0.43. For the group that did not receive the TAA training, the correlation was 0.028. These results agreed with the findings of Casner (2004) and suggested that total flight experience alone provides little or no intuitive guidance for the use of advanced avionics, nor can it serve as a substitute for learning and experience with advanced avionics. Advanced avionics proficiency appears to be a unique set of skills that must be learned in addition to basic airmanship.

Conclusion

The results suggested that time invested in mastering skills in a small technically advanced aircraft can have a significant impact on the subsequent learning of more sophisticated equipment. The systems now found in small technically advanced training airplanes appear to provide a simple, cost-effective way of introducing advanced avionics to pilots who are still in the formative phases of their professional aviation careers. This should alleviate the problem of new-hire pilots arriving to airline initial training programs with little or no experience in technically advanced cockpits.

We should be careful not to interpret pilots' performance with the jet simulator too literally. Pilots' performance using the jet simulator was scored on a task-by-task basis. Correctly performing a large proportion of tasks using a simulator does not necessarily add up to real-time successful operation of a jet aircraft in a full-mission flight environment. It is well known that the concurrent performance of the many individual tasks that make up the job of piloting an aircraft is a skill of its own: one that requires additional practice once the individual skills have been mastered. The most reasonable interpretation of the results presented here is that the small airplane training and experience places the pilot-in-training farther along in the learning process: shortening the time and effort required to train the future jet transport pilot.

A second issue, not directly addressed by this study, is the importance of learning underlying principles about the systems found in technically advanced aircraft, in addition to learning button-pushing procedures. Previous studies have demonstrated that learning focused on knobs, dials, and procedures results in fast training times, but also tends to result in brittle skills. These brittle skills are typically not transferable to other equipment, or problems and situations that are different from those initially learned. Kieras and Bovair (1984) demonstrated how students who received "how it works" explanations for a set of procedures they had learned were significantly more successful when presented with related problems that challenged them in different ways. Pennington, Nicolich, and Rahm (1995) conducted a similar study. Recognizing that conceptual learning can happen even when explicit conceptual instruction is not given, Chi, Bassok, Lewis, Reimann, and Glaser (1989) demonstrated how students generate and successfully apply their own "self-explanations" while solving problems.

Looking at Figures 1 and 2, we can see that the knobs, dials, and procedures used to operate the systems found in each airplane are different. The success of the group who received the TAA training can only be attributed to pilots' acquisition and application of generalized concepts and principles.

A future study could directly address the question of learning *generalizable* concepts and skills in three ways: (1) by measuring the effects of different amounts of conceptual explanations provided to pilots; (2) by examining the self-explanations generated by pilots in the absence of explicit conceptual instruction; and (3) by measuring pilots' ability to perform procedures that were not covered during training.

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